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FINAL ANNUAL REPORT

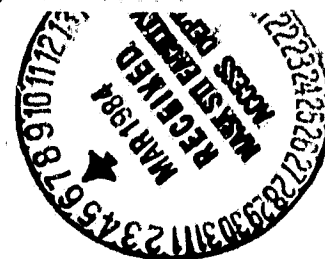
MUON SPIN ROTATION IN SOLIDS

VIRGINIA STATE UNIVERSITY

Supported by NASA grant NSG 1342

February 1983 - February 1984

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The February 1983 - February 1984 period saw several important developments in this research program. The most important was the development of a successful muon spin rotation facility at the Alternating Gradient Synchrotron of Brookhaven National Laboratory. During May 1983 this facility, which was proposed in 1978, finally came on line. During a run which lasted three weeks extensive beam studies were conducted and a preliminary measurement of muon depolarization in Al at low temperature with zero magnetic field was conducted. This beam provides about  $2,400 \mu^+$ /second on a sample  $1 \text{ in}^2$  in area, with 500 good events per second. Additional development work was done in July 1983 while the beam was off for the usual summer maintenance period. Preliminary preparations were made for a run which is anticipated to begin in March 1984. Virginia State University participants in the Brookhaven work include Carey E. Stronach (P/I of NSG 1342), John Bilodeau (former instructor of electrical engineering technology) and Lucian R. Goode (graduate student). Collaborators from other institutions include William J. Kossler (overall group leader of the Brookhaven MuSR effort) and three graduate students from the College of William and Mary, Anthony T. Fiory of Bell Laboratories, William F. Lankford of George Mason University, and Mohammed Numan of East Carolina University. It is expected that the aluminum data will be published in conjunction with results of related experiments to be done in the 1984 run.

A second major accomplishment was a set of MuSR experiments on nickel alloys, which was conducted at the Swiss Institute for Nuclear Research in

August/September 1983. Plots of these data are included as Appendix A to this report. These results will be reported at the Virginia Academy of Science meeting in May 1984 in Richmond, and at the Fifth Risø International Symposium on Metallurgy and Material Science in September 1984 in Roskilde, Denmark. The abstract of the latter is included as Appendix B and a paper on this work will be published in the Risø Symposium proceedings. Collaborators on these studies include Robert I. Grynspan of the Center for the Study of Metallurgical Chemistry, Vitry-sur-Seine, France, Pascal Dassonville (a doctoral candidate at the University of Paris), and Bruce D. Patterson of the University of Zürich. We anticipate further studies of nickel alloys at Brookhaven during the 1984 run and, possibly, additional experiments at the Swiss facility and/or the NIKHEF laboratory in the Netherlands. We expect that Lucian Goode will do his masters thesis on the results of the Brookhaven experiments on nickel alloys.

We are also pleased to report that a paper based upon the 1981/82 experiments upon uniaxially strained iron crystals (done at the Swiss facility) was accepted for publication by Hyperfine Interactions in mid-1983, and should appear in that journal in the near future. A preprint is included as Appendix C of this report. Finally, a paper which was accepted for publication in 1982 (in Electronic Structure and Properties of Hydrogen in Metals, Plenum Publishing Corp.) appears in that book, which was published in early 1983. A reprint is included as Appendix D of this report.

Two students have been supported by this grant in 1983-84. Lucian Goode is expected to complete his Master of Science thesis in MuSR by the end of the summer of 1984. Michael Davis is a sophomore who is also an experienced electronics technician. He has been doing repairs and routine maintenance upon a number of electronics units used in the MuSR experiments.

We are most pleased that NASA has supported this basic research, and

that this work is continuing to receive support (at a higher funding level) under NASA grant NAG-1-614. This new support, coupled with the success of the Brookhaven MuSR facility, should generate many exciting MuSR studies in the coming years.

Respectfully submitted,

*Carey E. Stronach*

Carey E. Stronach  
Principal Investigator  
February 28, 1984

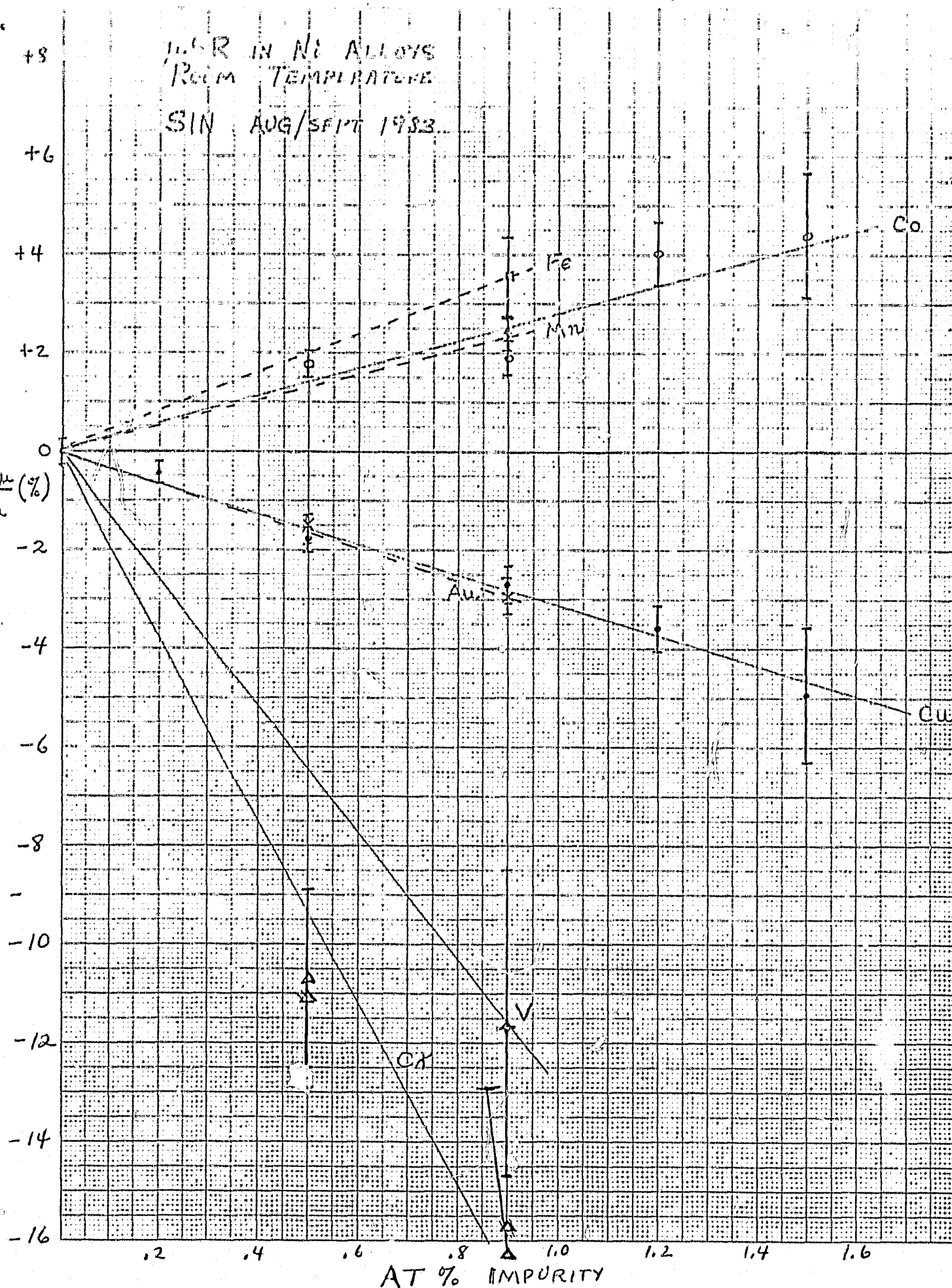
PER IN Ni ALLOYS  
ROOM TEMPERATURE

SIN AUG/SEPT 1983

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$\frac{\Delta B_{\mu}}{B_{\mu}}$  (%)

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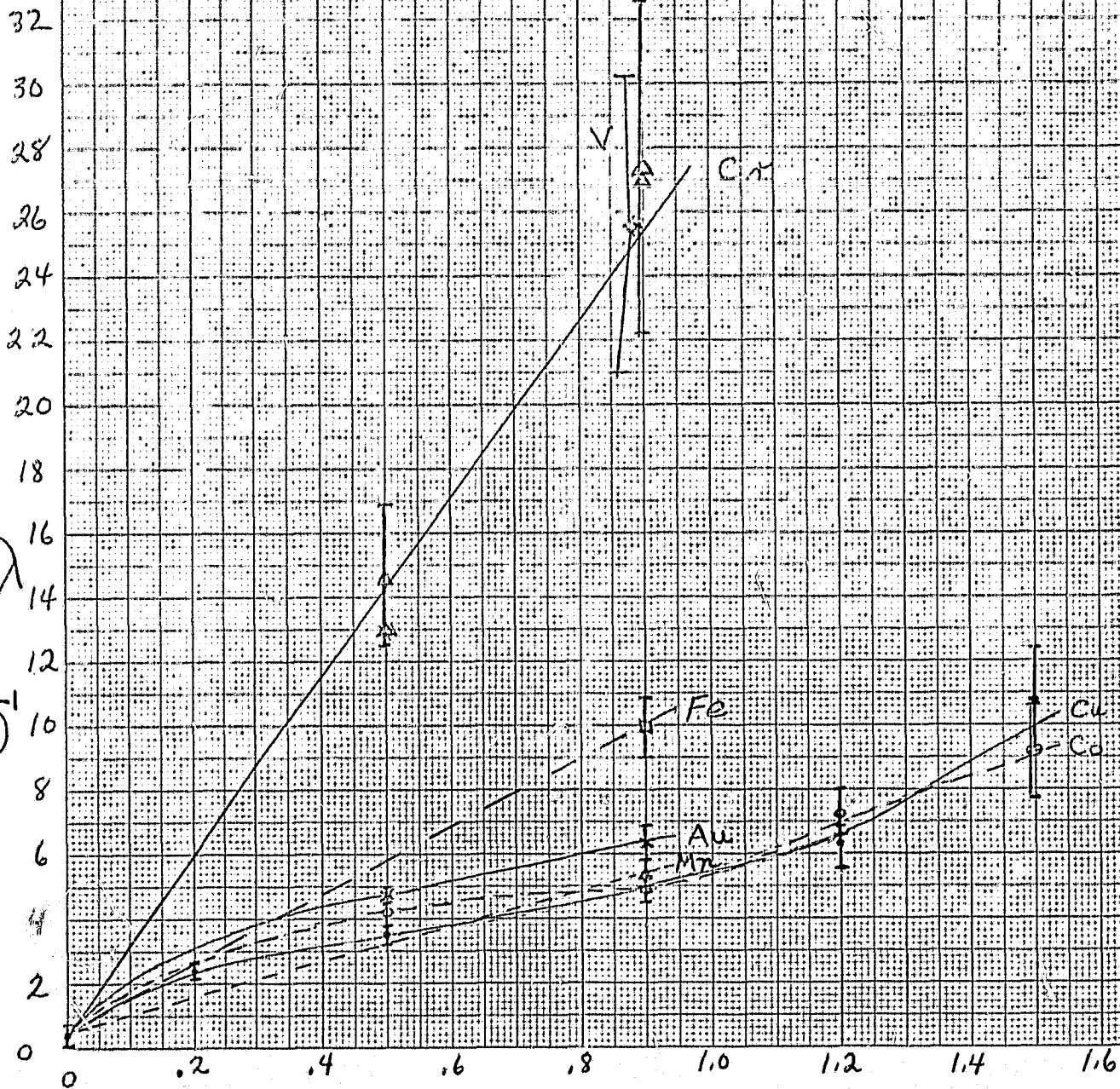
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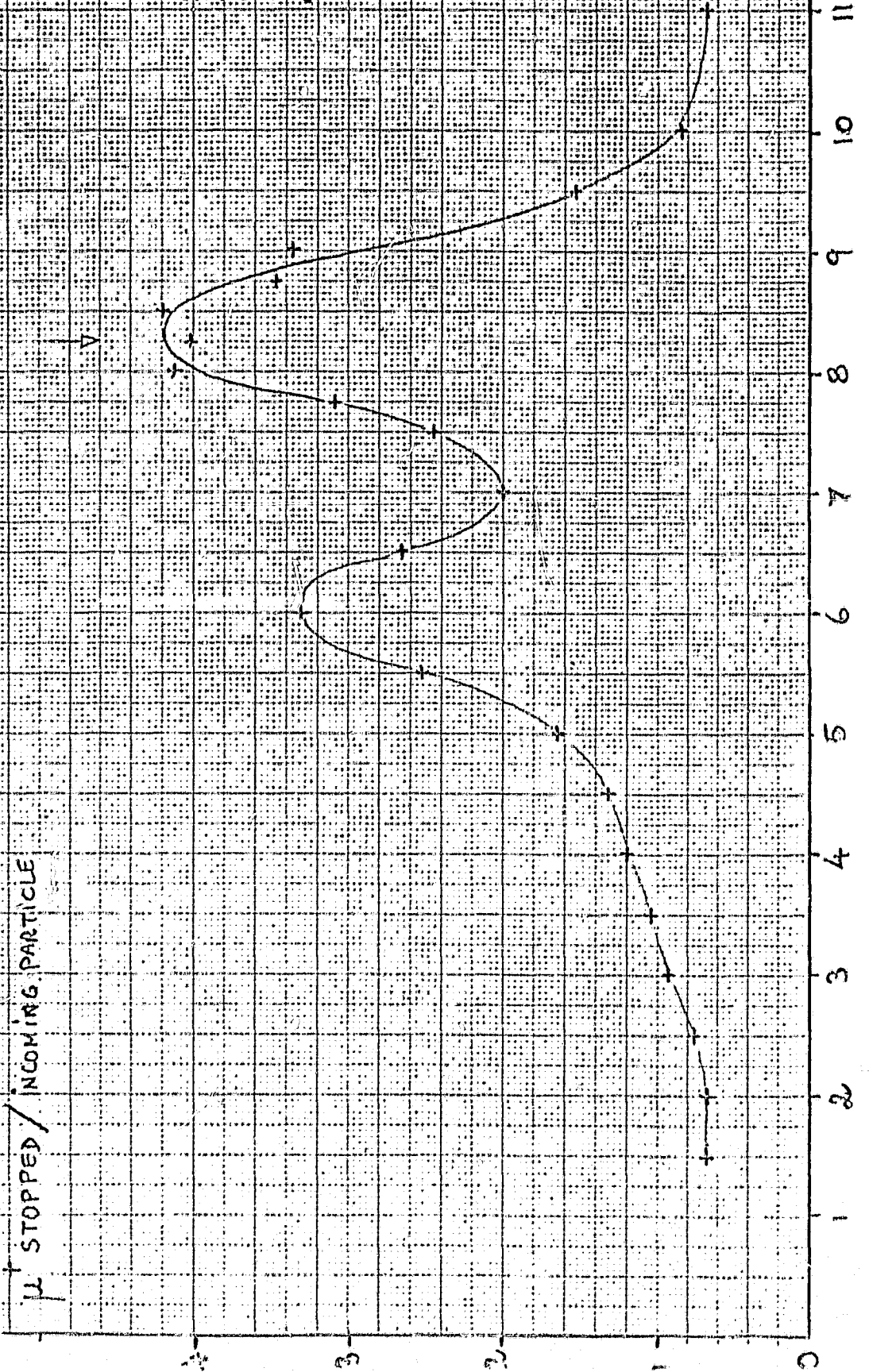
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Fifth Riso International Symposium on Metallurgy and Material Science  
MICROSTRUCTURAL CHARACTERIZATION OF MATERIALS  
BY NON-MICROSCOPICAL TECHNIQUES  
3-7 Sept. 1984 - Riso Natl. Lab., Roskilde, Denmark

THE INTERACTION OF POSITIVE MUONS WITH IMPURITIES IN NICKEL

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The Muon Spin Rotation ( $\mu$ SR) technique may be used to probe the microscopic electron density in materials. It is found that a positive muon implanted in a solid acts like a light proton ( $m_p/m_\mu = 9$ ), migrating among interstitial sites of the lattice and being attracted or repelled by chemical and/or structural defects (1).

In pure nickel at room temperature (RT), the muon feels a local magnetic field  $B_\mu = 0.1361(5)$  Tesla. When passing close to a defect it will sense a somewhat different field, and this will change the average  $B_\mu$  experienced by the ensemble of migrating muons in general by an amount proportional to  $C_x$ , the defect concentration ( $\Delta B_\mu/B_\mu = K_x C_x$ ). The constant of proportionality  $K_x$  will have a particular value  $K_{x0}$  (corresponding to simple dilution) for muon migration which is unbiased by the impurities (i. e. at sufficiently high temperature). The magnitude of  $K_x$  will be smaller or larger than that of  $K_{x0}$  if the muon is respectively repelled or attracted by the defect (2,3).

We report RT observations of average local field shifts in samples of nickel doped with up to 1.5 at. % of various metallic elements. Our results, in conjunction with the temperature dependent measurements of reference (2), suggest that impurities with full d electron shells (Cu, Au;  $K_x = -3$  % per at. %) tend to repel the muon whereas those lacking d electrons with respect to Ni (Co, Fe, Mn;  $K_x = +3$  to  $+5$  % per at. %) attract the interstitial muon. Negative values of  $K_x$  as large as  $-15$  % per at. % have been found for V and Cr impurities, indicating a large local change in the electron spin density. High temperature  $\mu$ SR and magnetization measurements are in progress to allow an unambiguous determination of the muon-impurity interaction and the impurity-induced change in the local spin density.

Additional examples will be mentioned, including interactions of muons with vacancies (4) and dislocations (5).

References:

- (1)- Positive Muons and Pions in Material Science, Editors J. Chappert and R.I. Grynszpan, North-Holland Publ., Amsterdam, in press (1984).  
(2)- W.J. Kossler, A.T. Fiory, W.F. Lankford, K.L. Lynn, R.P. Minnich, C.E. Stronach, Hyperfine Inter. 6 (1979) 93.  
(3)- C.E. Stronach, K.R. Quire, A.S. Arrott, B.D. Patterson, B. Heinrich, W.F. Lankford, A.T. Fiory, W.J. Kossler, J.J. Singh, J. Magnetism Magnetic Mater., 25 (1981) 187.  
(4)- A. Moeslang, H. Graf, G. Balzer, E. Recknagel, A. Weidinger, Th. Wichert, R.I. Grynszpan, Phys. Rev. B, 27(5) (1983) 2674.  
(5)- A.S. Arrott, B. Heinrich, C.E. Stronach, W.F. Lankford, J. Appl. Phys. 53(3) (1982) 1985.



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# Uniaxial Stress Induced Frequency Shifts for Muons in Single Crystal Fe

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Abstract: We report the first results on uniaxial stress-induced frequency shifts in an Fe single crystal. Stress was applied along the  $\langle 100 \rangle$  axis, which was also the axis of magnetization induced by an external field. The observed frequency shift was  $-0.34 \pm 0.023$  MHz per 100 micro-strain, which corresponds to  $\partial B_\mu / \partial \epsilon = +25.1 \pm 1.6$  G/100 $\mu\epsilon$ . The positive sign arises from the negative sign of  $B_\mu$  itself. This result is interpreted as follows: The stress induces a statistical population shift between magnetically inequivalent sites. Extrapolations from the calculations of Sugimoto and Fukai from Nb and V to Fe yield order of magnitude agreement. The  $4T(0)$  site system seems more likely.

## Introduction

We have measured the muonic precession frequency shift produced by uniaxial strain in an iron single crystal. The strain was along a  $\langle 100 \rangle$  direction, which was also the axis of magnetization which was induced by a

small applied field. The precession frequency is proportional to the average local magnetic field which is often decomposed with the usual definitions for the terms as:

$$\underline{B}_{\mu} = \underline{B}_{\text{ext}} + \underline{B}_{\text{dem}} + \underline{B}_L + \langle \underline{B}_d \rangle + \underline{B}_{\text{hf}}. \quad (1)$$

We are interested in the change of  $\underline{B}_{\mu}$  with applied uniaxial stress:  $\Delta \underline{B}_{\mu}$ . Changes in  $\underline{B}_{\text{ext}}$ ,  $\underline{B}_{\text{dem}}$  and  $\underline{B}_L$  are small for our purposes, and we find that the changes in the hyperfine field arising from its variation with distance from host lattice ions are small, based upon the results of Butz et al.<sup>1</sup> for precession frequency shifts under hydrostatic pressure. Differences in hyperfine field from one magnetically inequivalent site to another would need to be of the same order as the dipole field differences to be taken into consideration and there seems to be no mechanism to produce such large differences.

What remains, a change in  $\langle \underline{B}_d \rangle$ , is primarily from displacements of the nearest neighbor dipoles and from a change in the thermal average over the magnetically inequivalent sites. Thus we have

$$\Delta \underline{B}_{\mu} \cong -2/9 (\underline{B}_\ell - \underline{B}_t) \Delta E / kT + 1/3 (\underline{B}_\ell + 2\underline{B}_t) \quad (2)$$

where  $E = -(\frac{S_{11}-S_{12}}{S_{11}})(p_1-p_2)\epsilon_{100}$ ,  $S_{ij}$  are the elastic compliances for Fe,  $p_i$  are the diagonal elements of the double force tensor<sup>2</sup> for a muon in Fe,  $(B_\lambda - B_t)$  is the difference in magnetic fields for the magnetically inequivalent sites with tetragonal axes parallel or perpendicular, respectively to the magnetization axis, and  $\epsilon_{100}$  is the strain along the  $\langle 100 \rangle$  direction.  $B_\lambda + 2B_t = 0$  with no strain and is caused to be finite by strain induced displacement of magnetic dipoles on nearby Fe host lattice sites.  $B_\lambda$  and  $B_t$  depend strongly on site configuration, local lattice distortion, and the shape of the muon's wave function while undergoing zero point motion. The first term in Eq. 2 is, as it turns out, the most important.

### Experiment

These experiments were carried out at the  $\pi E 3$  port of the SIN accelerator using the Mili  $\mu$ SR apparatus. The surface muons passed through a  $2 \times 5$  mm collimator to stop in the sample held in the "puller" illustrated in Fig. 1. The temperature was approximately 300 K held constant by thermal contact to temperature controlled flowing alcohol. The long axis of the  $1 \times 4.6 \times 46.13$  mm<sup>3</sup> sample was the stress axis, the magnetization axis, and was within less than  $2^\circ$  of the  $\langle 100 \rangle$  crystallographic direction. The wide surface deviated from  $\langle 010 \rangle$  by about  $10^\circ$ . The sample was ARMCO iron from Monocrystals, Inc. Strain was measured directly on the sample with a strain gauge.

Positron detectors were upstream (B) and downstream (F) and the initial polarization of the muon was upstream and perpendicular to the  $\langle 100 \rangle$  long axis of the sample. Data were fit to:

$$N_{F/B} = N_{OF/B} e^{-t/\tau_\mu} \{ 1 + \frac{1}{2} P [ F_L e^{-t/T_1} + F_T e^{-t/T_2} \cos(\omega_\mu t + \phi) ] \} + B_{F/B} \quad (3)$$

$F_L$  and  $F_T$  refer to the fraction of the domains which are magnetized parallel and perpendicular, respectively, to the initial muon polarization. A plot of  $F_T/F_L$  versus  $B_{ext}$  is shown in Fig. 2. The initial value of 2.5 is not too far from 2 which would be expected for random domain orientations. Above  $B_{ext} = 150$  G  $F_T \gg F_L$  indicating nearly complete domain alignment.  $F_T/F_L$  remained high so long as the aligning field was present.

Figure 3 shows our result for precession frequency versus strain. The shift in frequency is  $-0.34 \pm 0.023$  MHz per  $100\mu$  strain. This corresponds to:  $\partial B_\mu / \partial \epsilon_{100} = +25.1 \pm 1.7$  G per  $100\mu$  strain. The opposite sign since  $B_\mu$  and  $B_{ext}$  are antiparallel.

### Discussion of the Results

To compare with experiment we must evaluate Eq. 2.  $B_\lambda$  and  $B_t$  have been calculated taking lattice site, lattice relaxation, and muon wave function into account. Results for  $B_\lambda$  are shown in Table I. Since the second term of Eq. 2 is much smaller than the first term we make comparison between a theoretically based  $(p_1 - p_2)_{th}$  and a  $(p_1 - p_2)_{exp}$  which fits the observed frequency shift.  $(p_1 - p_2)_{th}$  was obtained by extrapolating from the results of Sugimoto and Fukai<sup>3</sup> for the bcc Nb and V to Fe by the lattice parameter. Sugimoto and Fukai consider two site configurations for the muon which they call  $4T(0)$  and  $1T$ . The  $4T(0)$  site is an octahedral site with simultaneous occupancy of the 4 neighboring tetrahedral sites, while a  $1T$  site is a single tetrahedral site. This extrapolation yields:  $(p_1 - p_2)_{th} = 3.73$  eV  $4T(0)$  and  $-1.23$  eV  $1T$ . The experimental results were corrected for the smaller second term using the same percentage lattice distortion as Sugimoto and Fukai obtained for Nb and muon wavefunctions of similar extent ( $|\psi_\mu|^2 = \frac{1}{\alpha^2 \beta \pi^{3/2}} \cdot e^{-\frac{x^2 - y^2}{\alpha^2}} \cdot e^{-z^2/\beta^2}$ ;  $\alpha = 0.2a$ ;  $\beta = (1/\sqrt{2})\alpha$   $4T(0)$ ,  $\beta = \sqrt{2}\alpha$   $1T$ ). They are  $(p_1 - p_2)_{exp} = 1.8$  eV  $4T(0)$  and  $-3$  eV  $1T$ . There is order of magnitude agreement for either site, slightly better

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for the  $4T(0)$ . Even better agreement would be obtained for the  $4T(0)$  if the neighboring ions have their moments reduced by the presence of the muon.

Acknowledgements

We would like to thank W. Kündig and P. F. Meier for their hospitality, cooperation and tolerance. This work was supported in part by NSF Grant DMR 8007059 and NASA Grant NSG 1342.

References

- [1] T. Butz, J. Chappert, J. F. Dufresne, O. Hartmann, E. Karlsson, B. Lindgren, L. O. Norlin, P. Pondini and A. Yaouanc, Phys. Lett. 75A (1980) 321.
- [2] H. Kanzaki, J. Phys. Chem. Solids 2 (1957) 24.
- [3] H. Sugimoto and Y. Fukai, Phys. Rev. B 22 (1980) 670.

Figure Captions

Figure 1 Experimental Apparatus.

Figure 2  $F_T/F_L$  versus  $B_{ext}$ .  $F_T(F_L)$  is the fraction of domains aligned transverse (parallel) to the muon's initial polarization.

Figure 3 Muon precession frequency versus strain. The open circles represent the observed frequency observed immediately after the stress was released which produced the indicated strain for the full circle point.



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Table I. Dipolar Fields under Various Conditions

Lattice	Rigid	Relaxed			
		Point	$\alpha = \beta$ .15-.19	$\alpha = .19$ $\beta = .15$	$\alpha = .19$ $\beta = .25$
Muon	Point	Point			
$B_L$ (kG) $H_T(0)$	18.64	13.56	13	9.3	-
LT	-5.24	-3.73	-3.7	-	-4.8

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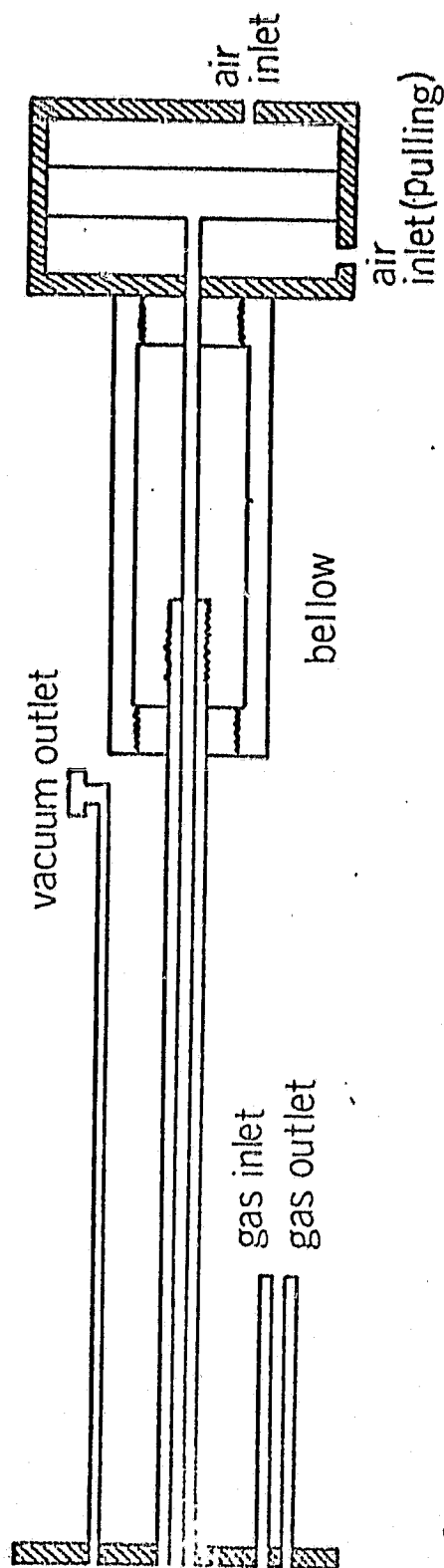
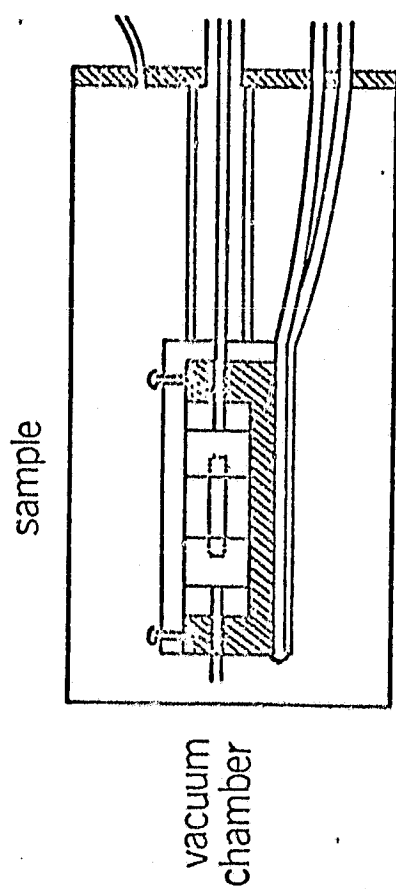


Fig. 1.

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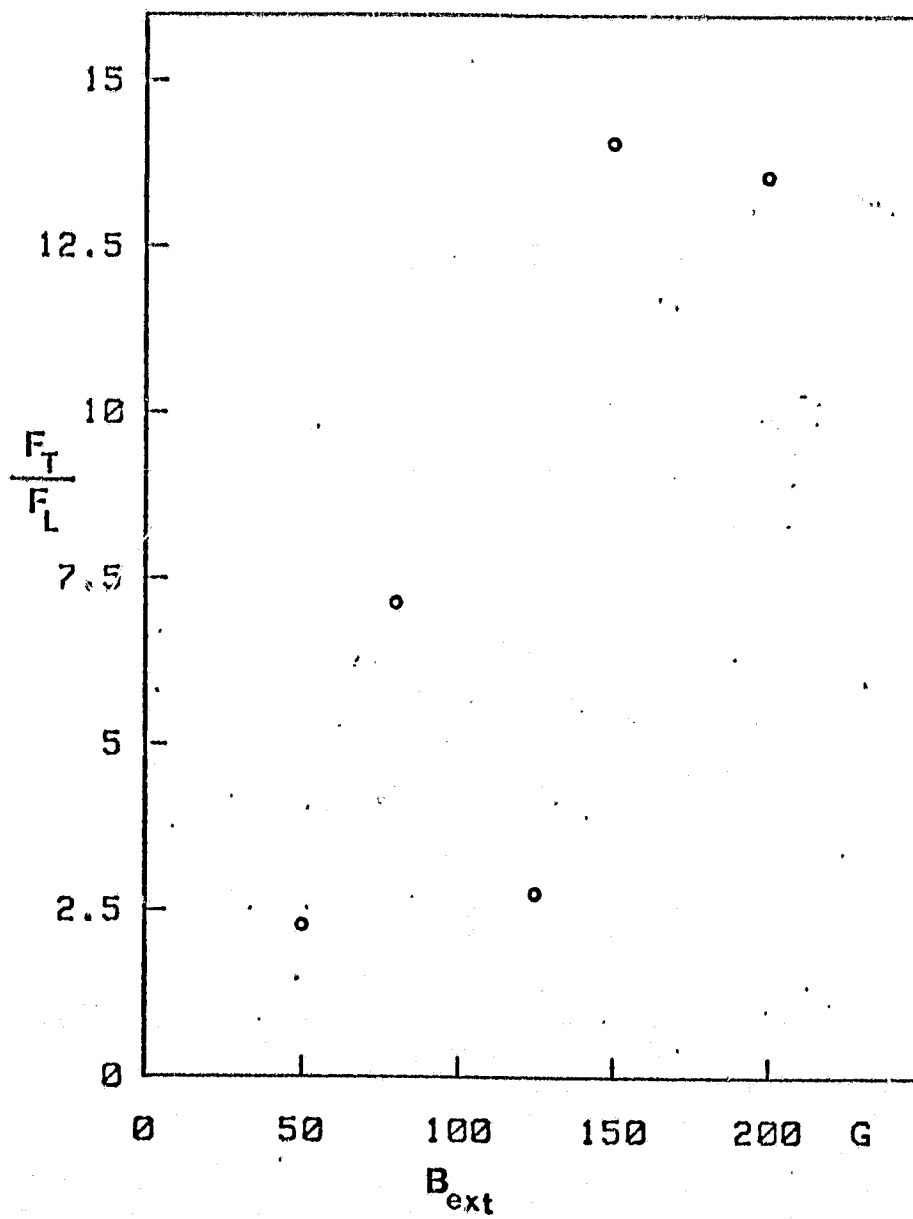


Fig. 2.

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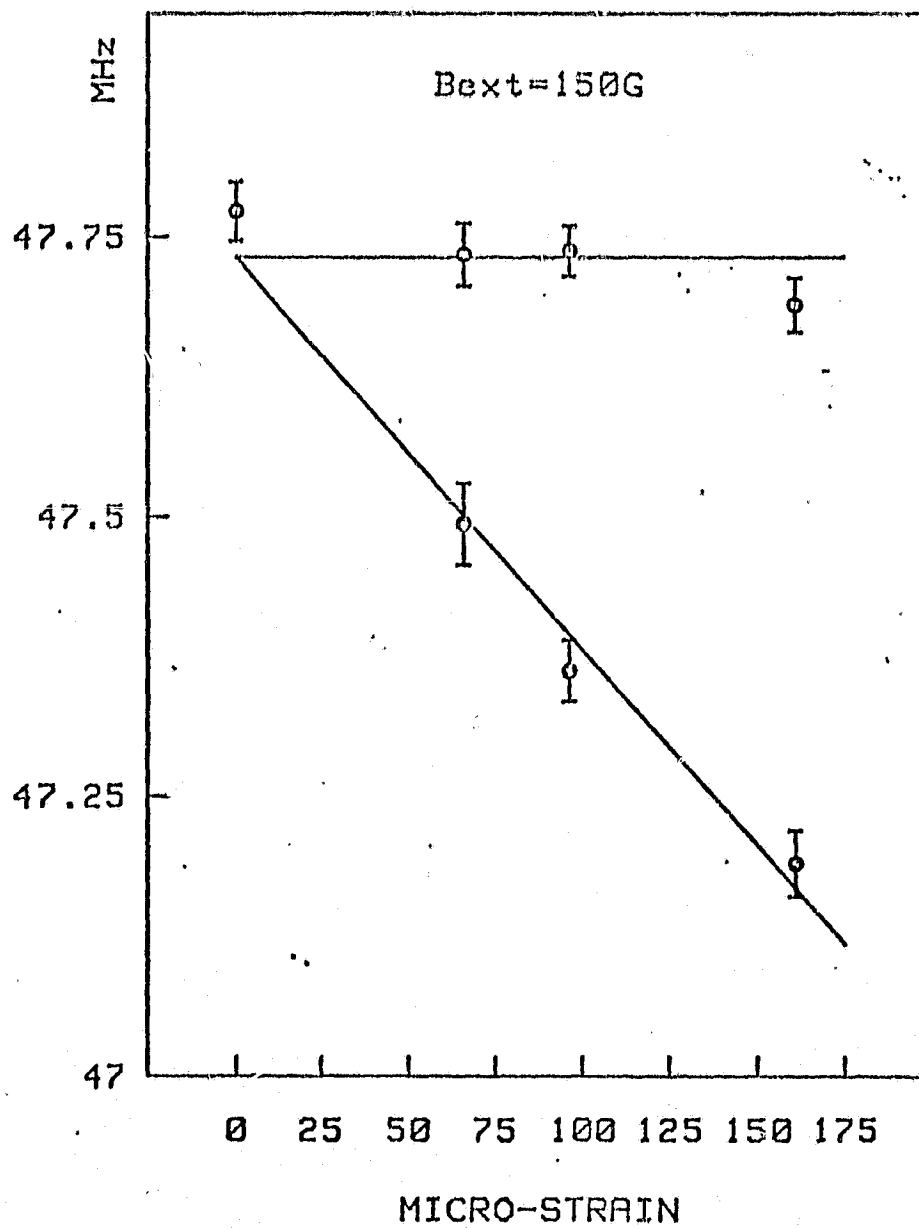


Fig. 3.

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BEHAVIOR OF POSITIVE MUONS IMPLANTED IN IRON ALLOYS

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ABSTRACT

Muon spin rotation measurements were made upon Fe alloyed with small amounts of N, Al, Si, Ge, Ti, V, Cr, Mn, Co, Ni, Nb, Mo and W. The measurements are described and the results are discussed in terms of the effect of impurities and associated strain upon  $B_\mu$  and  $B_{hf}$ .

INTRODUCTION

We employed  $\mu$ SR for a study of iron alloys. The time dependent angular correlation of the muon's positron decay precesses at  $13.552 \text{ MHz} \cdot B_\mu \text{ (KG)}$  where  $B_\mu$  is the average field sensed by a  $\mu^+$  implanted into the sample. See ref. 1 for more detail on the technique.

The experiments were conducted at the TRIUMF cyclotron facility. As previously mentioned, one obtains the local field  $B_\mu$  directly from the precession frequency. With no external field applied, and with the dipolar fields averaged to zero by the motion of the muon,  $B_\mu$  has only two major contributions, the Lorentz cavity field  $B_L = 4\pi M/3$ , and the contact hyperfine field  $B_{hf}$ , which arises from a polarized electron density about the  $\mu^+$ . The hyperfine field is then given by

$$B_{hf} = B_{\mu} - B_L$$

For Fe at room temperature  $B_L$  is about 7.2 KG and  $B_{\mu}$  is about -3.6 KG, so values for  $B_{hf}$  are of the order of -10.8 KG.

We parameterize the effect of the impurity upon the hyperfine field by calculating the fractional change in the hyperfine field, normalized to the impurity concentration,  $\Delta B_{hf}/c B_{hf}$ . For most of the alloys this has been determined only at room temperature, but for Fe(Mo) and Fe(Al) it has been measured over a range of temperatures.

#### HYPERFINE FIELDS

The table below summarizes our determinations of  $\Delta B_{hf}/c B_{hf}$  at room temperature:

Impurity	$\Delta B_{hf}/c B_{hf}$
N	-8
Al	-0.23
Si	-0.42
Ge	0
Cr	-0.09
Mo	-0.72
W	-0.79
Ti	-1.3
V	-1.10
Cr	-0.09
Mn	-1.10
Co	0.2
Ni	-4.4

If an impurity served only to dilute the hyperfine field by acting as a non-magnetic hole at a substitutional lattice site, with random site sampling by the  $\mu^+$ , one has  $\Delta B_{hf}/c B_{hf} = -1$ . We note that Mo, W, V and Mn approximate such behavior at room temperature, while Cr, Al and Si decrease the magnitude of  $B_{hf}$  considerably less than predicted by pure dilution. These results for Al and Si may be at least partially explained by the mechanism described in ref. 2, in which the temperature dependence of  $B_{hf}$  in Fe(Al) was measured. An increase in  $\Delta B_{hf}/c B_{hf}$  with increasing temperature suggests that  $\mu^+$  are repelled from solutes with p-wave bonding electrons, and thus experience smaller site effects. Even so, the high-temperature limit (or random sampling limit) of  $\Delta B_{hf}/c B_{hf}$  for Fe(Al) is still only  $\approx -0.35$ .

Co, which increases both the moment per Fe atom and the Curie temperature ( $T_c$ ), is the only solute which makes  $B_{hf}$  more negative. Ge, which also increases the moment per Fe atom and  $T_c$ , has the next most positive effect, zero.

Cr is out of line in both the vertical Cr, Mo, W and horizontal W, Cr, Mn sequences in the periodic table. To the best of our knowledge there is no other characteristic of these alloys for which this is seen. We can only speculate that Cr impurities produce less internal strain in the crystals than the other impurities do.

Ti, Ni and N impurities produce very large reductions in the magnitude of  $B_{hf}$ , each being several times the prediction of pure dilution. Again, this may be due in part to non-random site sampling by the  $\mu^+$ . The temperature dependence of  $B_{hf}$  was measured for Fe(Mo) and it showed an effect opposite to that found for Fe(Al): the  $\mu^+$  is apparently attracted to Mo impurity sites in Fe.<sup>3</sup> The effect of Ti is about double what one would obtain if  $B_{hf}$  were reduced to zero at all sites adjacent to Ti impurities. Studies of Fe(Ti) at higher temperatures show that while  $|\Delta B_{hf}/c B_{hf}| \gg 1$ , it is decreasing with increasing temperature. This suggests that the Fe(Ti) result may arise, in part, from preferential sampling by the  $\mu^+$  of sites adjacent to Ti atoms.

A study of the temperature dependence of  $B_{\mu}$  in Fe(Ge) showed an hysteresis effect upon annealing (Fig. 1). The form of the  $B_{\mu}(T)$  curve changed upon annealing, apparently because of the release of internal strains in the annealing process.

A large decrease in  $B_{\mu}$  was found in the two-phase alloy Fe + Fe<sub>2</sub>Nb, compared with the pure Fe from the stock material from which all the alloys were formed. This sample consists of Fe<sub>2</sub>Nb inclusions in a pure Fe matrix. Two samples with different Nb concentrations showed that the reduction in  $B_{\mu}$  is more pronounced with greater Nb concentration. This is contrary to the naive expectation that, since all  $\mu^+$  spin rotation takes place in the pure Fe, the frequency of the signal would be unchanged by the Fe<sub>2</sub>Nb inclusions with only the amplitude changing. This reduction in magnitude of  $B_{\mu}$  is of the order of magnitude of Fe anisotropy fields around inclusions and may result from weak trapping of the  $\mu^+$  around these inclusions.

#### STRAIN EFFECTS

The observation that in some cases the presence of impurities in Fe decreases the magnitude of  $B_{hf}$  more than pure dilution, the shift of  $B_{\mu}$  in Fe(Ge) upon annealing, and the decrease in the magnitude of  $B_{\mu}$  with addition of Fe<sub>2</sub>Nb inclusions all lead us to the



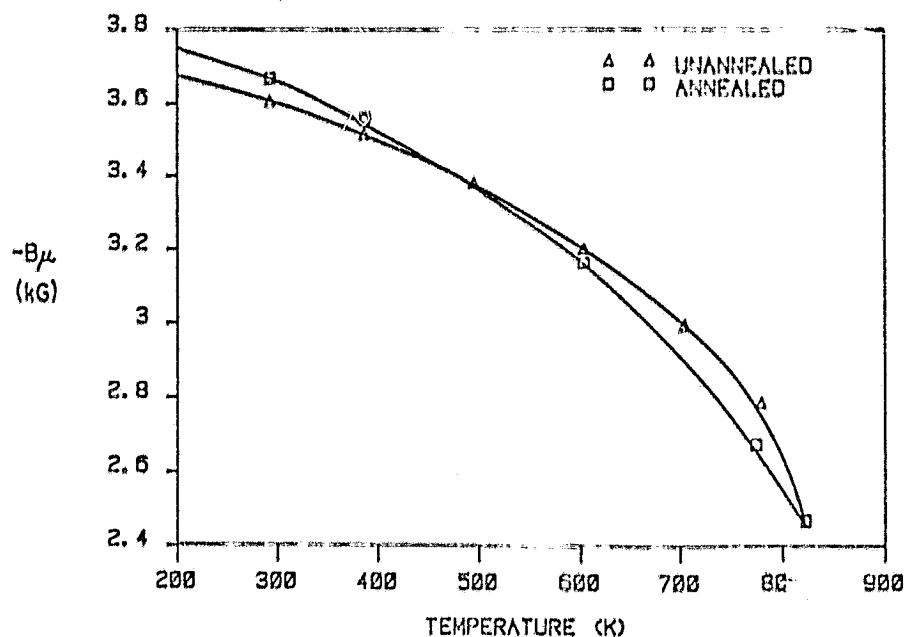
$B_{\mu}(T)$  IN FE ALLOYED WITH 1.54 AT. % GE

Figure 1

belief that strain plays a major role in determining the field seen by the  $\mu^+$ .

Shear strains break the symmetry of the dipole lattice in Fe. With complete bcc lattice symmetry the diffusion of the  $\mu^+$  averages the dipolar fields to zero. However, shear strains could give a net dipolar field perpendicular to the magnetization. Computer simulations of these fields show that the net effect upon  $\mu^+$  is to decrease the precession frequency.<sup>4</sup>

The recent observation that uniaxial tension decreases  $B_{\mu}$  in single crystals of Fe supports the notion of strain sensitivity to  $B_{\mu}$ .

#### HIGH TEMPERATURE MEASUREMENTS

The problem of non-random sampling of sites by the  $\mu^+$  can presumably be overcome by providing the muons with sufficient thermal energy that  $kT$  is much greater than the attractive/repulsive potentials at interstitial sites adjacent to impurity atoms. Measurements at such high temperatures (approaching  $T_c$ ) are fraught with difficulties. Assuming that the practical problem of constructing ovens

which can maintain stable gradient-free high temperatures is over-  
come, one must also determine the magnetization of the alloy as a  
function of temperature. This varies rapidly near  $T_c$ , and the  
approximation heretofore used of scaling the magnetization curve of  
pure Fe to the  $M(T = 0K)$  and  $T_c$  values of the alloy probably is not  
sufficiently accurate. Therefore both precision  $\mu SR$  experiments and  
magnetization measurements will be necessary to fully exploit this  
area of study.

#### ACKNOWLEDGMENTS

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A. T. Fiory and B. D. Patterson participated in the initial studies  
of Fe alloys.

#### REFERENCES

1. W. F. Lankford, K. G. Lynn, W. J. Kossler, A. T. Fiory, R. P.  
Minnich and C. E. Stronach, Nucl. Instr. and Meth. 185 (1981)  
469.
2. C. E. Stronach, W. J. Kossler, J. Lindemuth, K. G. Petzinger,  
A. T. Fiory, R. P. Minnich, W. F. Lankford, J. J. Singh and  
K. G. Lynn, Phys. Rev. B20 (1979) 2315.
3. C. E. Stronach, K. R. Squire, A. S. Arrott, B. D. Patterson,  
B. Heinrich, W. J. Lankford, A. T. Fiory, W. J. Kossler and  
J. J. Singh, Jour. of Mag. and Mag. Mat. 25 (1981) 187.
4. A. S. Arrott, B. Heinrich, C. E. Stronach and W. J. Lankford,  
J. App. Phys., in press.
5. W. J. Kossler, M. Namkung, R. I. Grynspan, C. E. Stronach,  
B. D. Patterson, W. Kündig and P. F. Meier, private  
communication.